

Adhesion Tests of Candidate Backsheets and Encapsulants



Gary Jorgensen, John Pern, Joe DelCueto,
Steve Glick, Kent Terwilliger, Tom McMahon

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Summary of Materials & Tests as f(exposure)

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Materials: Encapsulants Backsheets					
EVA (STR 15295P)					
Modified EVAs					
EPDM (BRP)					
Silicones identified last meeting					
THV					
Others					
NREL PE-CVD coated PET					
AKT PE-CVD coated PET					
PNNL multi-layer coated PET					
Isovolta coated laminates					
Others (Al foil laminate, LCP, +)					

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Summary of Materials & Tests as f(exposure)

Materials: Encapsulants Backsheets Combined B + E	Scotch Tape Peel Test	90°/180° Peel Strength	Lap Shear Strength	WVTR	Corro -sion Protec -tion
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EVA (STR 15295P)		Gary	Mike		
Modified EVAs		Gary			
EPDM (BRP)			Mike	Mike	
Silicones identified last meeting			Mike	Mike	
THV			Mike		
Others		Gary			
NREL PE-CVD coated PET	Gary	Gary		Kent	
AKT PE-CVD coated PET	Gary			Kent	
PNNL multi-layer coated PET	Gary	Gary		Kent	
Isovolta coated laminates		Gary		Kent	
Others (Al foil laminate, LCP, +)		Gary		Kent	
Combined B + E					Kent

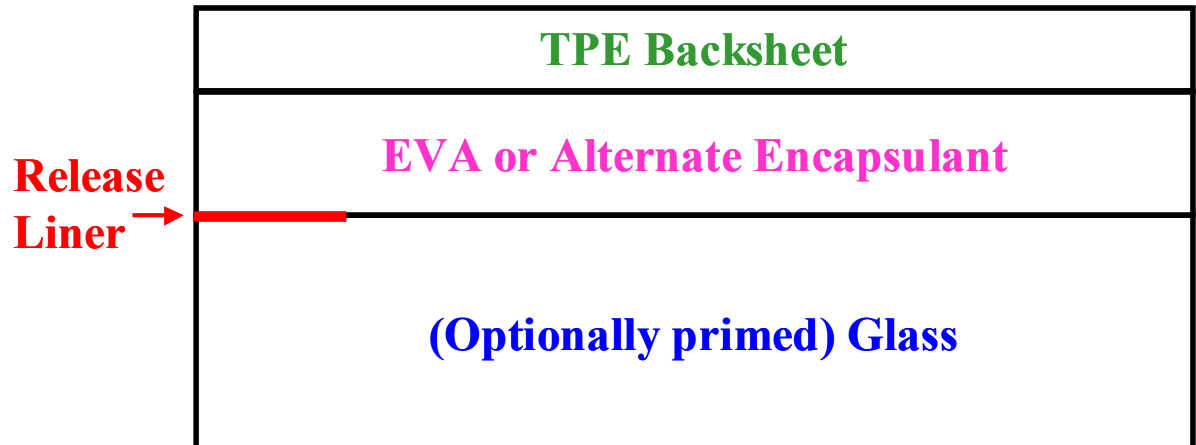
Acknowledgements

- John Pern (NREL): EVA / primed glass substrate samples and alternate encapsulants
- Joe DelCueto and Steve Glick (NREL): PE-CVD coated PET backsheets
- AKT: PE-CVD coated PET backsheets
- Larry Olson (PNNL): multilayer coated PET backsheets
- George Bukovinszky (First Solar): Isovolta backsheets
- Stan Levy: Experimental laminate backsheet; THV

Encapsulants

- Silane adhesion promoters screened
 - Use candidate formulations to prime glass substrates
 - Construction = TPE / EVA / Primed glass
 - Measure 90° peel strength between EVA and glass as function of damp heat exposure
- Alternate encapsulants also evaluated

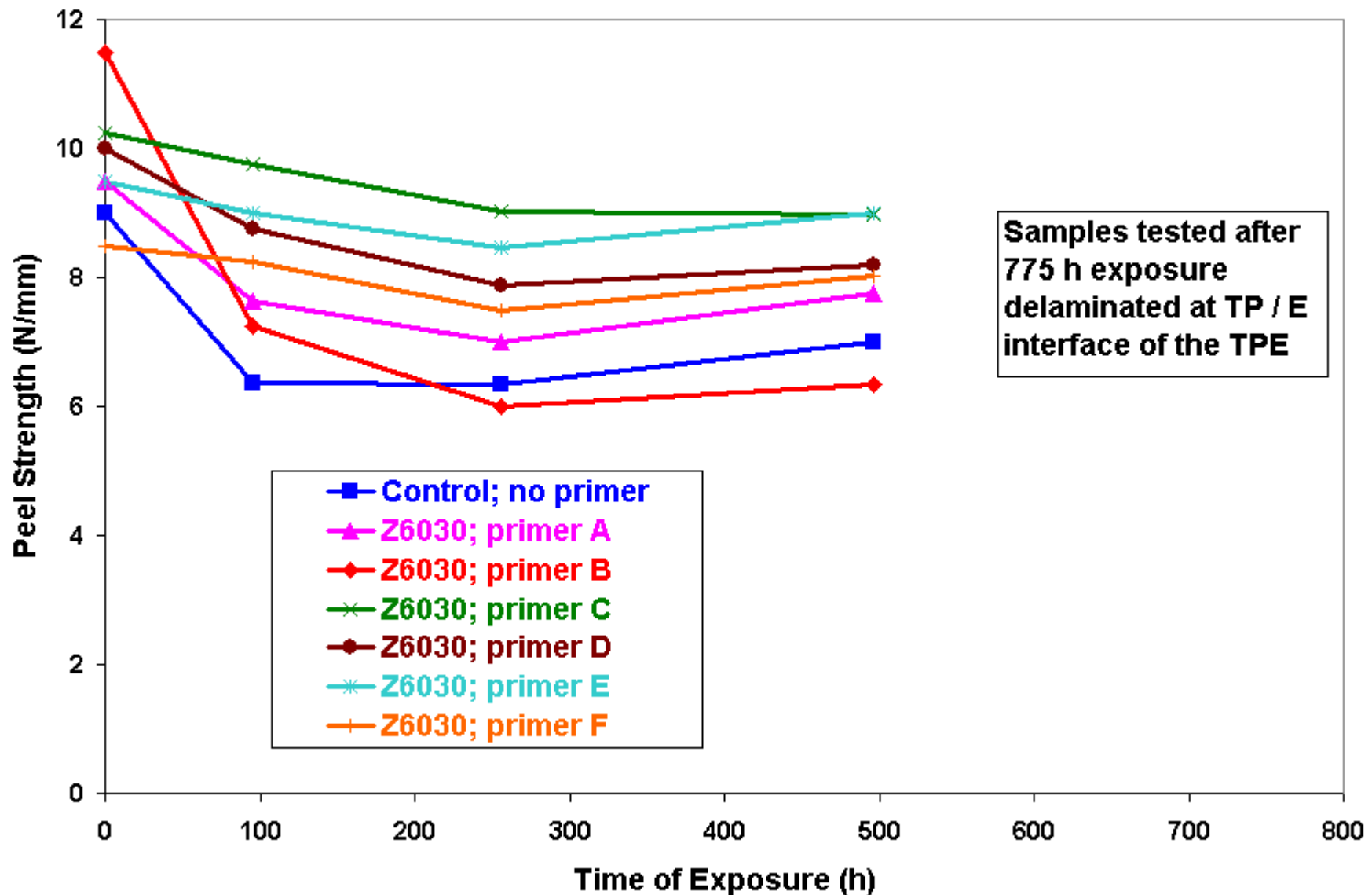
**Sample
Construction:**



Screening of Silane Adhesion Promoters

Sample ID	Base Silane	Silane 2 (S2)	Silane 3 (S3)	S2 (%)	S3 (%)
Control (EVA 15295P self-priming encapsulant only; no glass priming treatment)					
Z-6030-A	Z-6030	N/A	N/A	0	0
Z-6030-B	Z-6030	Amino-	N/A	25	0
Z-6030-C	Z-6030	Vinyl-	N/A	x	0
Z-6030-D	Z-6030	Dipodal	N/A	x	0
Z-6030-E	Z-6030	Fluoro-	N/A	x	0
Z-6030-F	Z-6030	Vinyl-	Amino-	x	5
Z-6030-G	Z-6030	Fluoro-	Amino-	x	5
Z-6030-H	Z-6030	Dipodal	Amino-	x	5
Z-6030-I	Z-6030	Epoxy-	Amino-	x	y
Z-6030-J	Z-6030	Fluoro-	Dipodal	x	y
Z-6030-K	Z-6030	Diamino-	N/A	25	0
Z-6030-L	Z-6030	Phenyl-	N/A	25	0
Z-6030-M	Z-6030	Phenyl-	Diamino-	25	5
Z-6030-N	Z-6030	Phenyl-	Diamino-	25	10
Z-6030-O	Z-6030	Phenyl-	Diamino-	25	25
Z-6030-P	Z-6030	Phenyl-	Diamino-	50	10
Z-6030-Q	Z-6030	Phenyl-	Diamino-	75	10
Z-6030-R	N/A	Phenyl-	Diamino-	90	10
Z-6030-S	Z-6030	Phenyl-	Dipodal	x	y
Z-6032-A	Z-6032	Vinyl-	Amino-	x	y
Z-6032-B	Z-6032	Dipodal	Amino-	x	y
Z-6032-C	Z-6032	Vinyl-	Diamino-	x	y
Z-6032-D	Z-6032	Phenyl-	Diamino-	x	y

90° Peel Strength of EVA / Primed Glass Interface as a Function of Damp Heat Exposure



Analysis of Silane Primer Data

Use Time-Averaged Peel Strength as measure of adhesion:

$$\hat{S}_p = \frac{\int_0^{t_{max}} S_p(t) dt}{\int_0^{t_{max}} dt}$$

Can then define a test criterion that depends on the estimated standard deviation (σ) of the acquired data and the percentiles of the studentized range (q):

$$w = \frac{q_{1-\alpha} \cdot \sigma}{\sqrt{n}}$$

For $n = 13$ treatments to be compared and $\alpha = 0.99$ (99% confidence level), $w = 1.29$

Effectiveness of Silane Primers

Primer	Rank	\hat{S}_p	$\Delta\hat{S}_p$	Cum $\Delta\hat{S}_p$	Cum $\Delta\hat{S}_p$
Z6030-J	1	9.56	0.24	2.8	1.18
Z6030-C	2	9.32	0.05	2.56	0.94
Z6032-B	3	9.27	0.12	2.51	0.89
Z6032-A	4	9.15	0.32	2.39	0.77
Z6030-E	5	8.83	0.17	2.07	0.45
Z6030-G	6	8.66	0.26	1.9	0.28
Z6030-I	7	8.4	0.02	1.64	0.02
Z6030-D	8	8.38	0.46	1.62	
Z6030-F	9	7.92	0.34	1.16	
Z6030-A	10	7.58	0.25	0.82	
Z6030-H	11	7.33	0.4	0.57	
Z6030-B	12	6.93	0.17	0.17	
Control	13	6.76			

$w = 1.29$

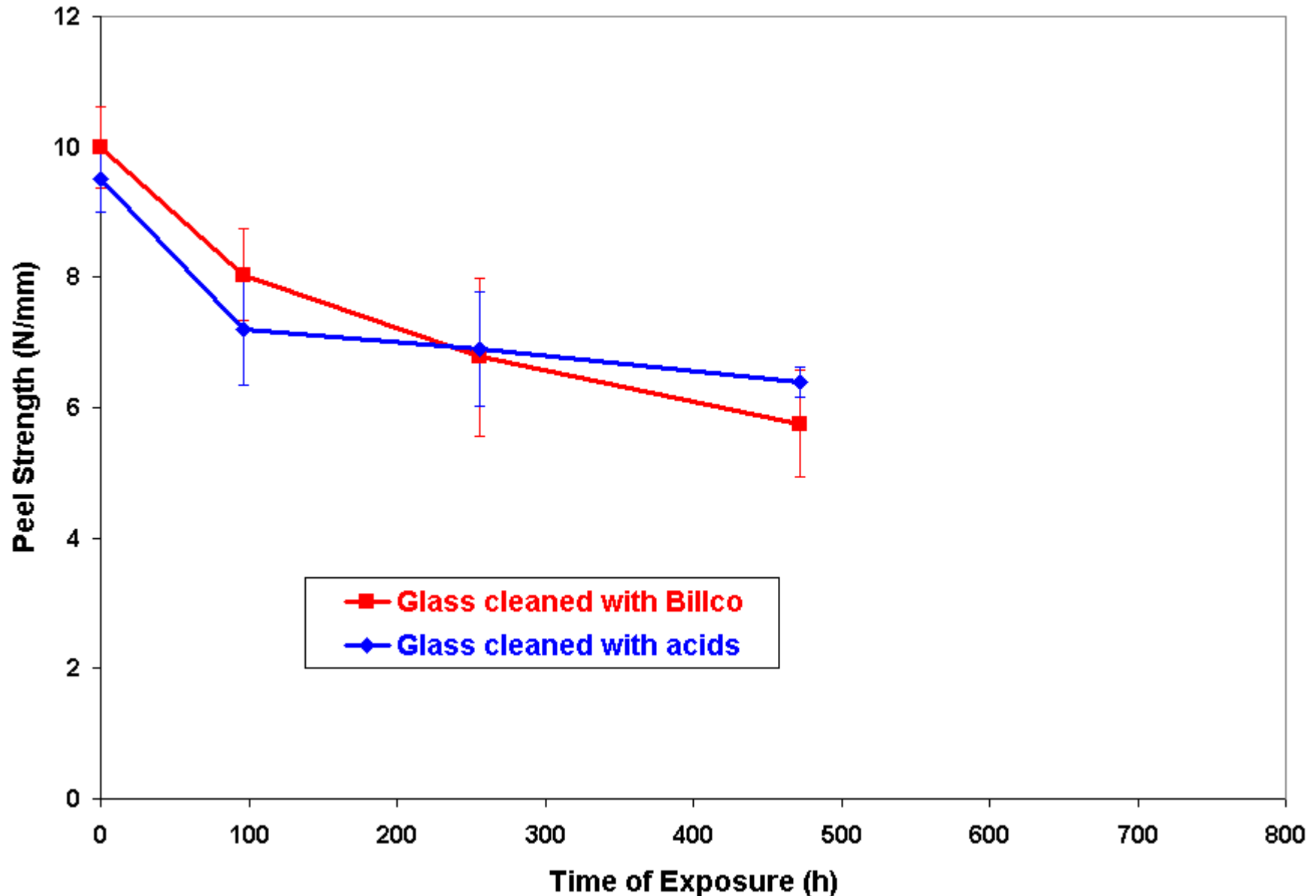
Test Results for Primed Glass Samples

- Primed glass samples Z6030-A, B, F, and H indistinguishable from the control
- Primed glass samples Z6030-C, D, E, G, I, and J + Z6032-A and B are improved compared with the control
- Ranking among improved samples is not statistically significant
- Peeling of samples Z6030-J and Z6032-A and B did not initiate at glass interface, even after 775 h damp heat exposure

Glass Substrate Cleaning

- Studied effect of glass substrate cleaning procedure on adhesion to 15295P EVA
 - Isopropyl alcohol + Billco (pH \sim 5.5-5.9) wash
 - Liqui-Nox + EtOH + HCl/MeOH + H₂SO₄
- Measured contact angles of cleaned glass
 - Billco \sim 52°
 - Acids \sim 5°
- After almost 500 h damp heat exposure, no difference in peel strength of EVA/Glass interface

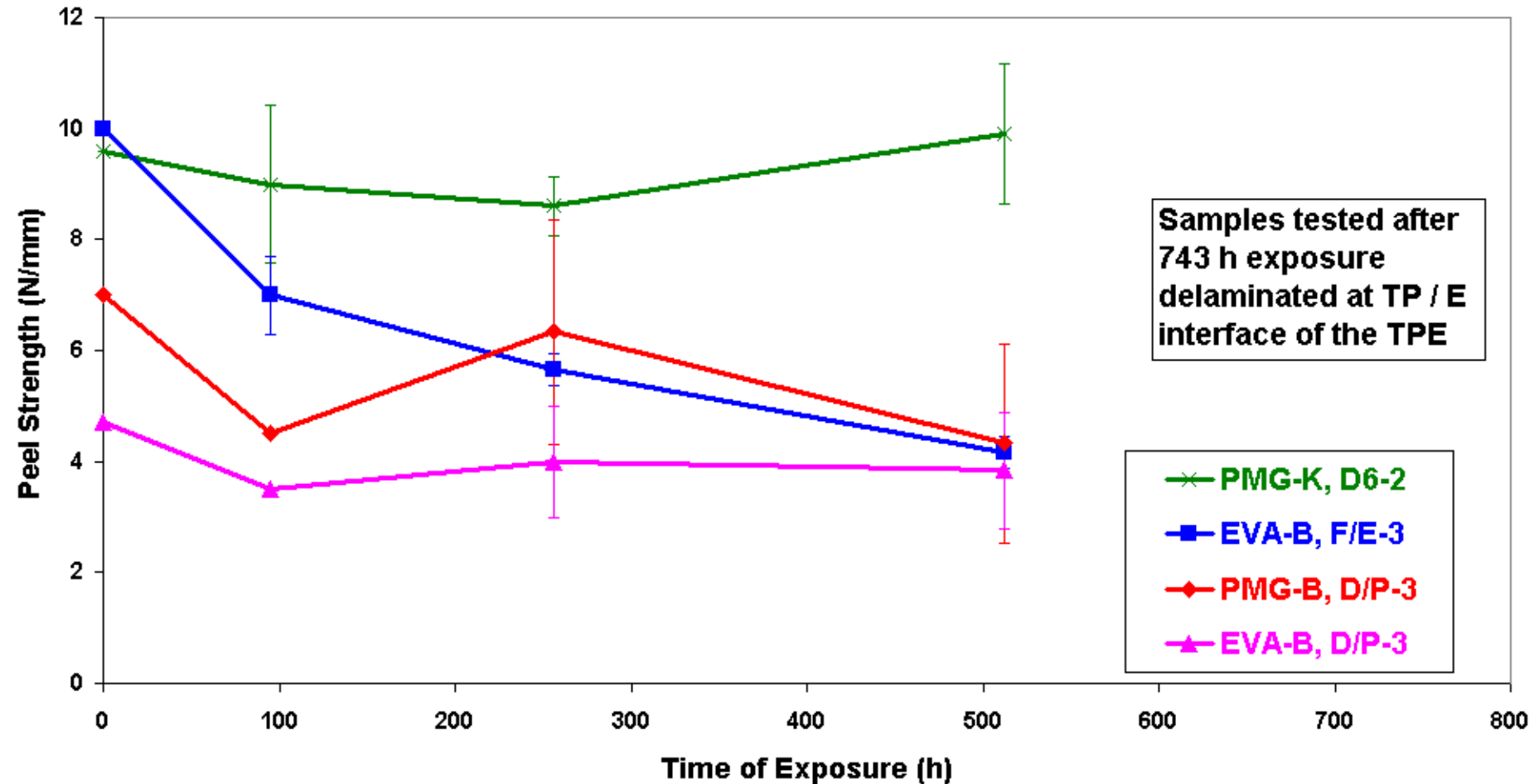
90° Peel Strength of STR EVA / Glass Interface for 2 Cleaning Methods as a Function of Damp Heat Exposure



Alternate Encapsulants

- NREL-prepared alternate encapsulant formulations are also being tested
 - EVA
 - Ethylene copolymer of methacrylate with glycidyl functional groups
 - Various silanes incorporated
- Some materials similar or inferior in performance to STR's 15295P EVA
- One material (PMG-K, D6-2) very promising; no peel initiation after 743 h damp heat exposure

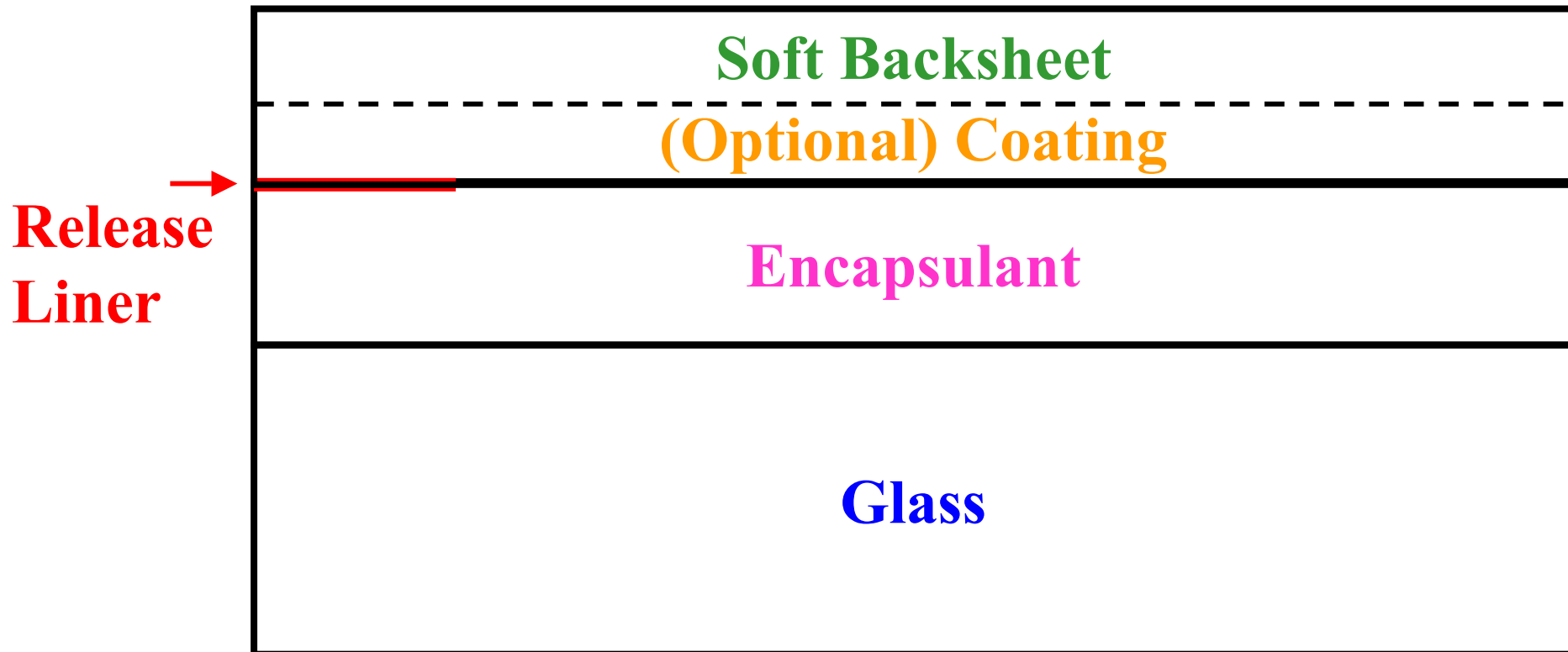
90° Peel Strength of Alternate Encapsulant / Glass Interface as a Function of Damp Heat Exposure



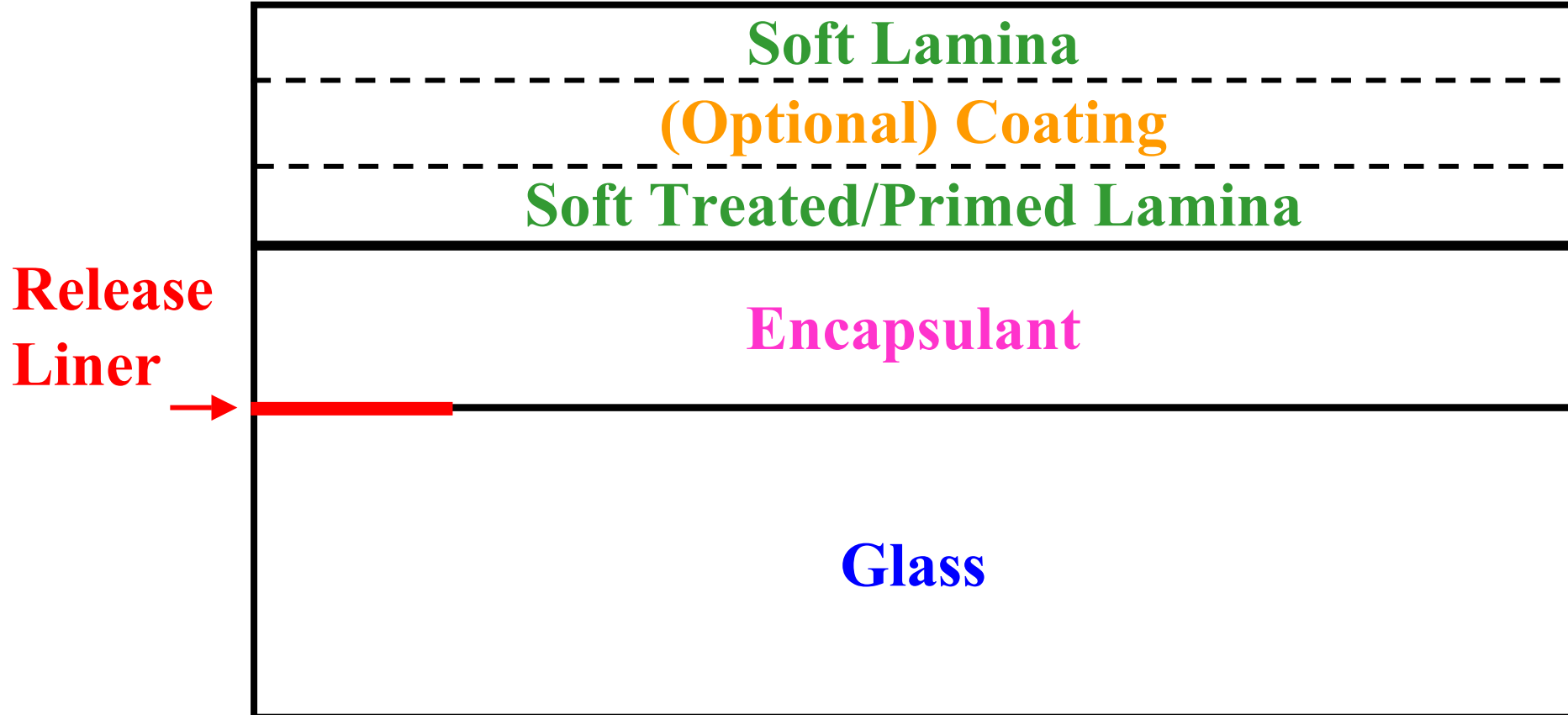
Testing Effectiveness of Backsheets

- NREL PE-CVD coated PET
- AKT PE-CVD coated PET
- PNNL multilayer coated PET
- Isovolta coated laminates
- PEN / Al / PET laminate

Construction of Coated PET Peel Strength Test Samples



Construction of Commercial Backsheet Peel Strength Test Samples



NREL PE-CVD Coated PET

- NREL PE-CVD system activated
- Several coated PET samples have been prepared
- Coatings pass initial tape peel test but fail with damp heat exposure
- Adhesion of coating laminated to EVA high at $t=0$ but delaminates with damp heat exposure
- Continuing to explore effect of process parameters on stoichiometry, morphology, adhesion, and moisture transport properties

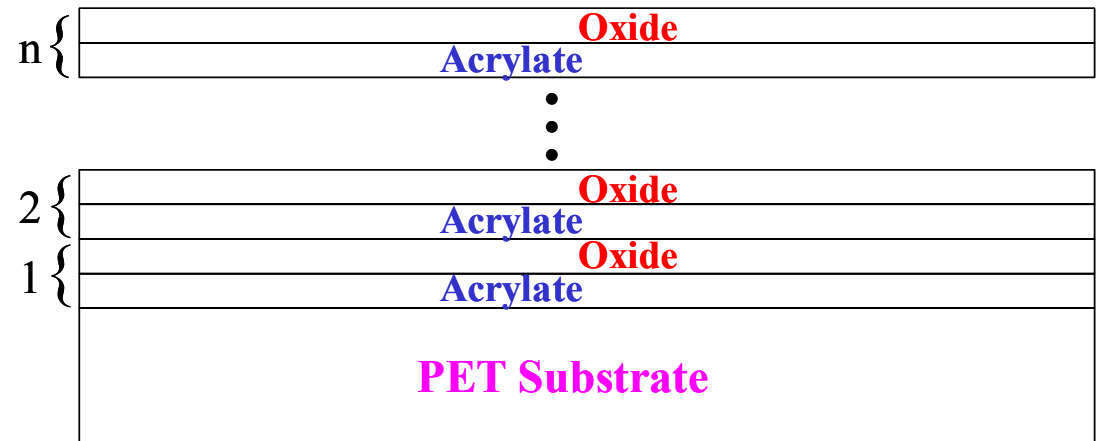
AKT PE-CVD Coated PET

- AKT provided 10 new PE-CVD coated PET samples
 - SiN_x vs. SiON_x
 - Different thicknesses
 - Different surface pre-treatments
- 3 samples passed tape peel test up to 612 h damp heat exposure; 2 still pass after >1250 h

PNNL Multilayer Coated PET

- Multilayer = oxide / acrylate
- 3- and 5-multilayer coated PET samples received
- Both multilayer coatings pass the tape peel test up to 634 h of damp heat exposure (fail after 967 h)
- Multilayer coated PET does not laminate to EVA; problem being investigated

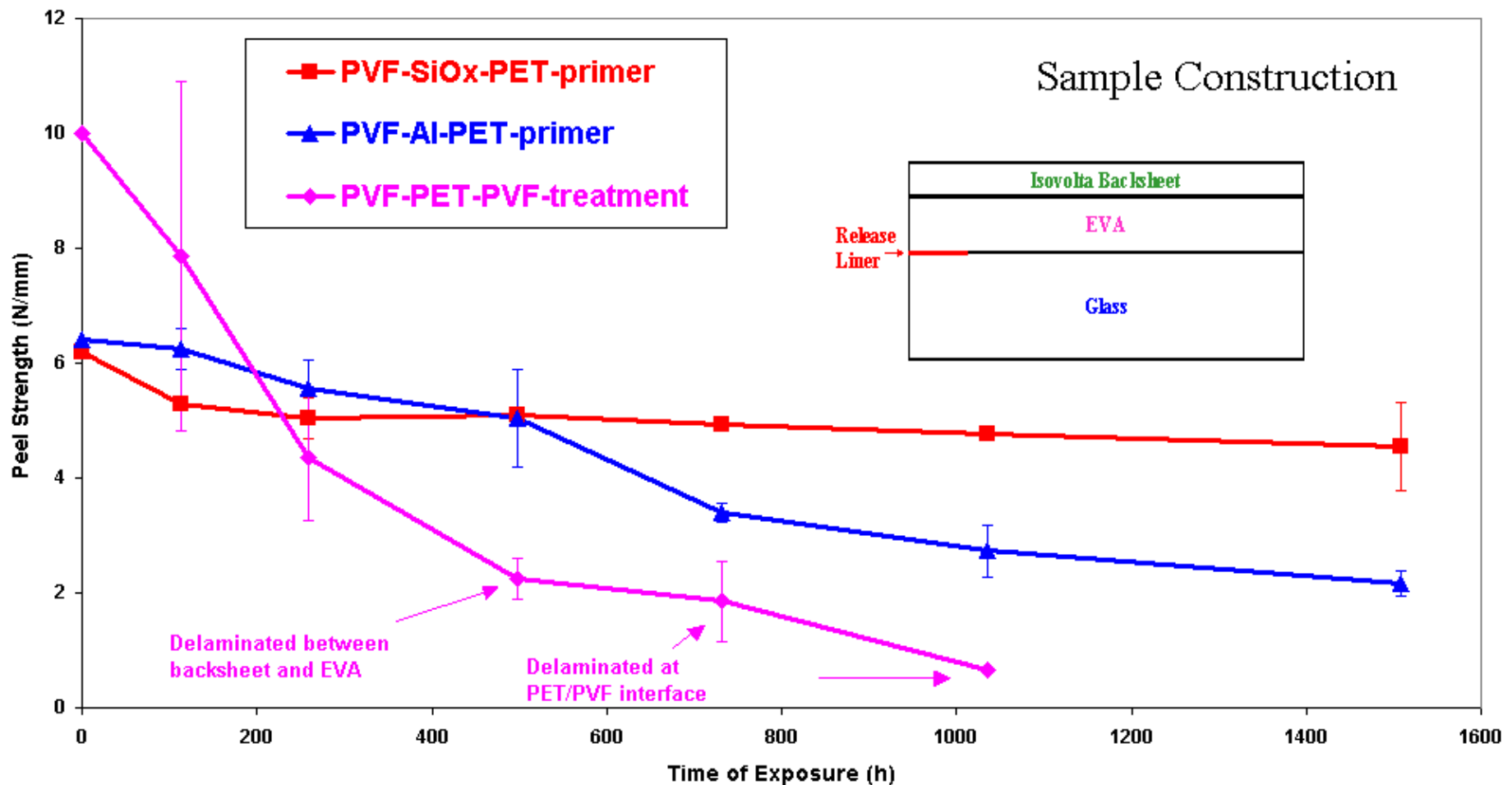
**Construction of
sample with
n-multilayer
coating:**



Isovolta Coated Laminate Backsheets

- Three materials tested
 - PVF-PET-PVF-treatment (Isosolar 2442)
 - PVF-SiO_x-PET-primer (Isosolar 2836)
 - PVF-Al-PET-primer (Isosolar 2116)
- Interested in how well the backsheet protects the EVA/Glass interface during damp heat exposure
- Isosolar 2836 provides best long term protection (although ~26% loss in peel strength after 1500 hours exposure)
- Isosolar 2442 exhibits interlayer delamination with damp heat exposure

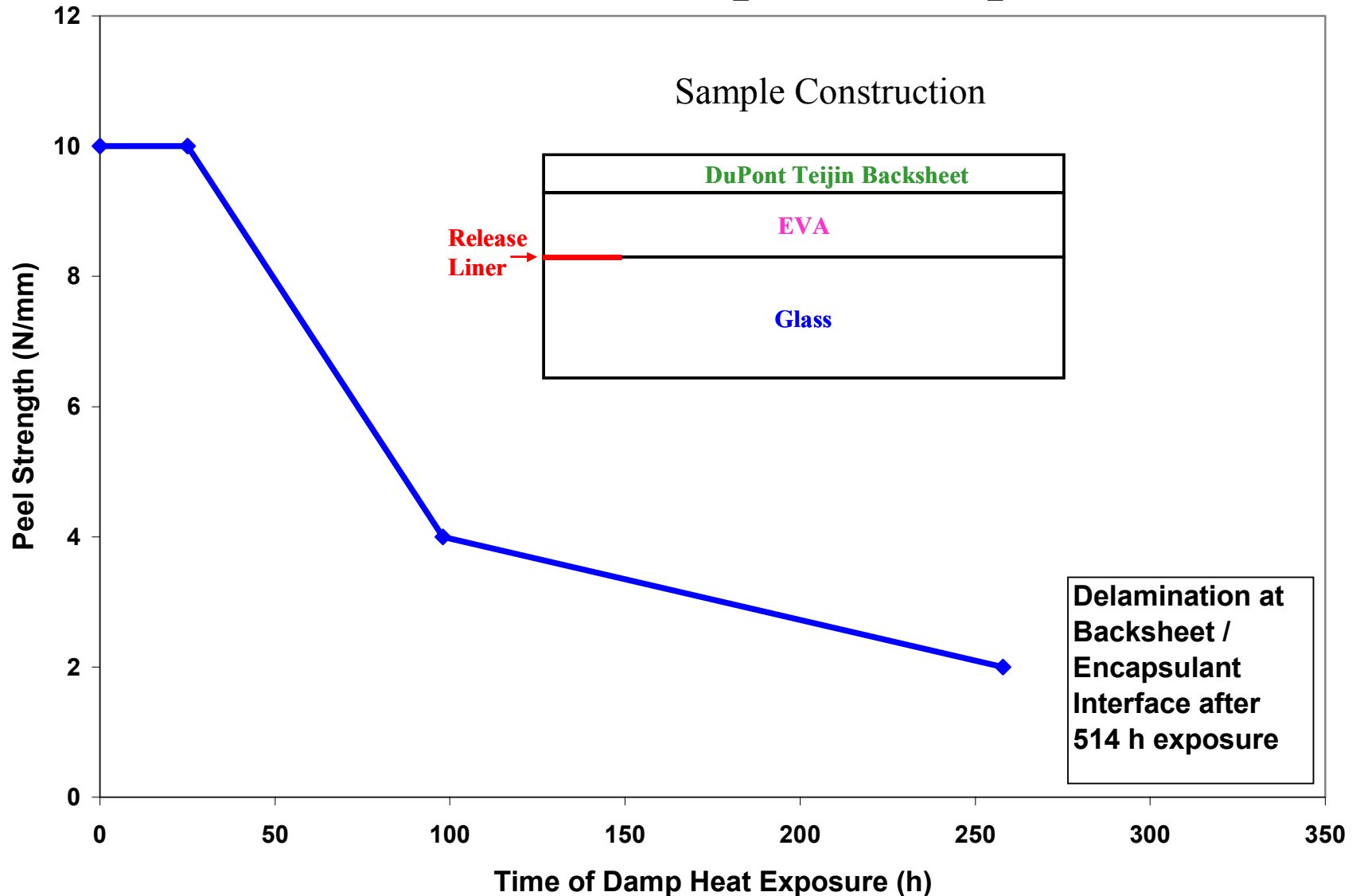
180° Peel Strength of EVA/Glass Interface (with Isovolt Backsheets) as a Function of Damp Heat Exposure



DuPont Teijin Experimental Laminate

- Construction = PEN / Al foil / Treated PET
- Outstanding moisture barrier properties
- Interested in how well the backsheets protect the EVA/Glass interface during damp heat exposure
- Excellent adhesion after 25 h exposure; peel strength degrades thereafter
- Delamination of treated PET from EVA after 514 h exposure

180° Peel Strength of EVA/Glass Interface (with DuPont Teijin Experimental Laminate Backsheet) as a Function of Damp Heat Exposure



Conclusions / Future Work

- Silane primers identified that enhance EVA adhesion to glass during damp heat exposure
 - Need to compound primers into EVA for further testing
- Standard industry glass cleaning procedure comparable to acid cleaning
- Improvements required for advanced coated PET backsheets
 - Efforts in early stages; need time to progress
- Several industry-provided backsheets (commercial and experimental) evaluated
 - Different levels of moisture ingress protection provided
 - Additional development could produce improved products